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Developments in Communication Materials[1]

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The subject of engineering materials is one of increasing importance, as is evidenced by the expenditure of over a half billion dollars annually in new construction by the Bell System. This has led to the concentration of the research and engineering work on materials in a group devoted particularly to this field of activity. Studies of the chemical and physical properties of materials must be combined by the materials engineer with a knowledge of the operating requirements of telephone apparatus.

The paper covers broadly the materials used in communication engineering and gives instances in which the needs of the telephone plant imposed requirements which were not satisfied by commercially available materials. Some of the instances cited are phenol fiber having improved resistance to arcing for use in sequence switches; a composite molded plastic for use in terminal strips; textile materials for central office wiring treated to improve their electrical insulating quality and non-ferrous metals of more uniform characteristics. Problems involving the use of duralumin for radio broadcasting transmitters and the light valve used in sound pictures are also described. Particular emphasis is laid on the benefits resulting from the continuous research in magnetic materials which have produced successively—powdered electrolytic iron cores for loading coils, permalloy, and recently perminvar.

Summing up, the work on materials has resulted in benefits along two general lines:

1. Improvement in quality of commercial materials.
2. Discovery or development of valuable new materials.

THE subject of this paper, "Developments in Communication Materials," perhaps needs some definition with the rapid addition of new fields to the pioneer arts of telegraphy and telephony. Today we must include high frequency wire telegraphy and telephony by means of carrier currents, radio, telephotography, television and, in a sense, sound pictures. All of these modes of communication of intelligence are characterized by the use of electrical means for the transfer of the signal, sound or scene to distant points, or their recording.

Up to about ten years ago the average manufacturer left to his designing engineer the problem of selecting and testing the materials which were to be embodied in a design, and he in turn was dependent on the manufacturers of raw materials as to the variety and quality of the materials available. Without depreciating the ability or initiative of manufacturers of engineering materials, it will be evident that the special needs of a particular industry would, in general, not be as fully appreciated by an outside manufacturer as by an engineer working

[1] Presented before A. I. E. E. on November 13, 1929.

on these problems. Thus it has come about in the Bell System, as with other large consumers of materials, that the investigation of materials has been organized as a distinct branch of research and engineering activity. Studies of the chemical, physical and metallurgical properties of materials are embraced in this work. In general the materials engineer should not only be well versed in materials, but should also have a good knowledge of the operating characteristics of the apparatus to be designed. Thus he can discuss the materials side of the problem with the designing engineer on equal terms and make his contribution to the best advantage. The importance of a thorough knowledge of materials in the telephone business will be appreciated from the fact that, during 1929, it is estimated that about $590,000,000 will be spent for additions to the Bell System plant.

In telephony the general introduction of the dial system has imposed more severe requirements than heretofore because of the need for the utmost in reliability of performance of the large number of switches, relays, etc., which are required to operate automatically with a minimum of maintenance. In the central office small size of apparatus constitutes a very important consideration, not only because of building space required, but the mass and travel of the automatic switches have an important effect on the speed with which connections can be established and hence on economy of operations. Thus, close control of the quality of materials and the need for small, compact apparatus are important design considerations.

In a brief survey of progress in the development of materials, it will be necessary to select a few typical items of interest. The items selected deal primarily with the telephone problem as this is, at the present time at least, the largest single factor in the communications group. The subject may be divided broadly into insulating materials and metallic materials.

Insulating Materials

Phenol Fiber

Considering first sheet insulating material, we have been using the term "phenol fiber" to cover such materials as bakelite-dilecto, micarta, formica and similar fibers made by various manufacturers. Phenol fiber is used extensively in telephone apparatus. One of its applications is in the sequence switch which has insulators alternating with conducting segments, as shown in Fig. 1. The sequence switch, which is used in the dial system, draws out an arc when in operation which sometimes causes carbonization of the insulators. In some cases a hole was burned through the insulator and in other cases the arc was

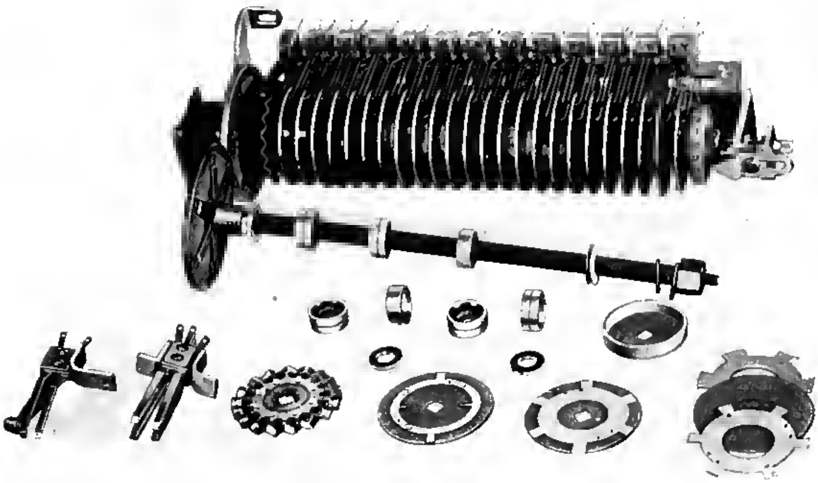

Fig. 1—Sequence switch, used in dial system.

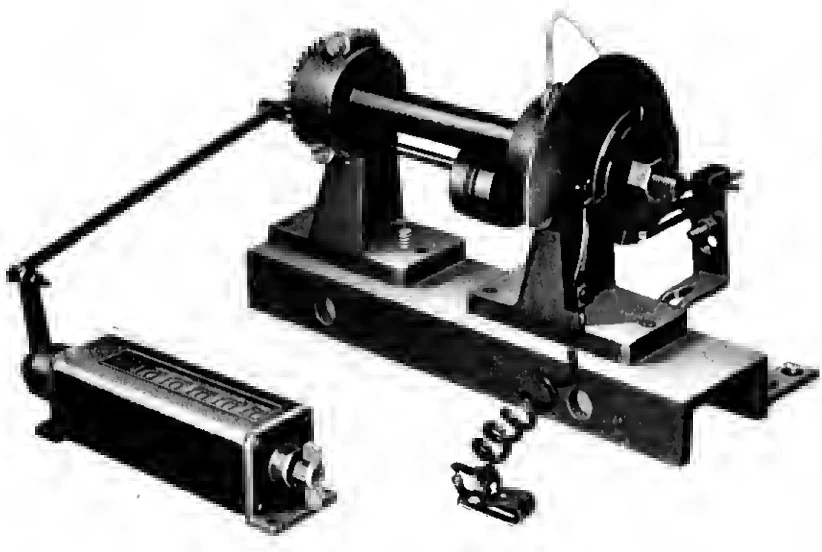

Fig. 2—Detail of apparatus for arcing test of phenol fiber.

sustained over the insulation to such an extent that the circuit was not broken at the proper moment. An examination of the various grades of phenol fiber commercially supplied indicated that they varied widely as to their resistance to arcing. Fig. 2 shows testing apparatus designed to evaluate this characteristic.

The sample under test was made into a sequence switch cam and rotated on the fixture at a speed of 10 r.p.m. The set is wired to give a circuit condition comparable with that causing failure in service, except that slower speed and higher voltage are used to accelerate the test. The position of the rear brush is so adjusted that after the material has become carbonized through an arc of 15 degrees or a hole has been burned through the insulation, the machine would be stopped by means of a circuit breaker, shown in Fig. 3. This instrument makes the

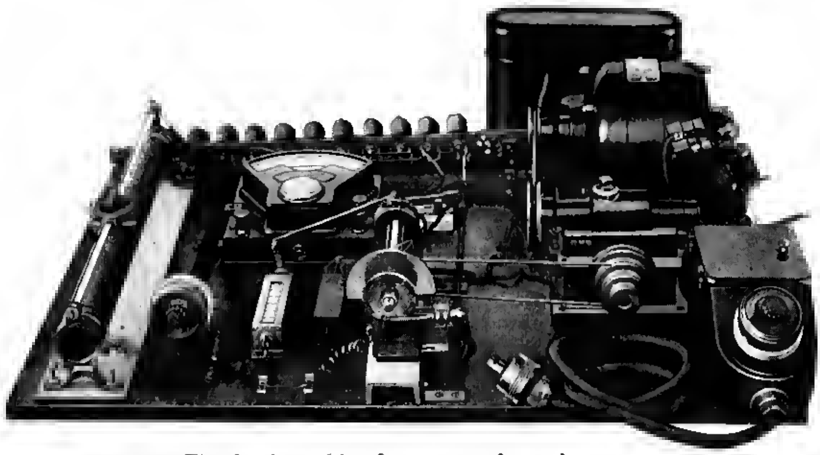

Fig. 3—Assembly of apparatus for arcing test.

failure value independent of the operator's judgment, and has proven so satisfactory that it has been employed for specification purposes.

Fig. 4 shows insulators tested by this instrument; those at the top having been rejected, and those at the bottom being satisfactory. An improvement of 20 to 1 in arcing characteristics was obtained. This was brought about by close cooperation with the Bakelite Research Laboratories, which developed a special grade of resin to be used in the manufacture of this material. In this case the materials engineer developed a method of test for evaluating the particular quality desired which enabled the supplier to improve his product in the desired respect.

Even though resistant to moisture in the ordinary sense, phenol fiber absorbs a certain amount of moisture depending on the quality of the material furnished. As this moisture is given up, the material

Fig. 4—Insulators subjected to arcing test.
Top—Failure value, 20 rev.
Bottom—Failure value, 1200 rev.

Fig. 5—Telephone relay showing phenol fiber insulators between contact springs.

tends to shrink. If the fiber is not sufficiently hard as manufactured, it will also flow under pressure.

In telephone relays of a commonly used type, illustrated by Fig. 5, the contact springs are insulated from each other by thin sheets of phenol fiber, and any material change in dimensions of these insulators, due to moisture absorption or cold flow, will alter the spacing of the contacts, thus throwing the relay out of adjustment. To measure these tendencies on materials used in spring pile-ups, we use the method illustrated by Fig. 6. It will be seen that a Brinell machine, usually

Fig. 6—Modified Brinell machine for flow-test of insulator laminations.

employed for metals testing, has been modified to use a flat-ended plunger resting on a pile of insulating material. The test material is first cut into pieces ½″ square and then subjected to atmospheric conditions which would cause it to take up an amount of moisture comparable to that expected under manufacturing conditions. The pieces are then stacked and a pressure of 2,000 pounds per square inch applied. The testing apparatus is installed in a heat insulated box

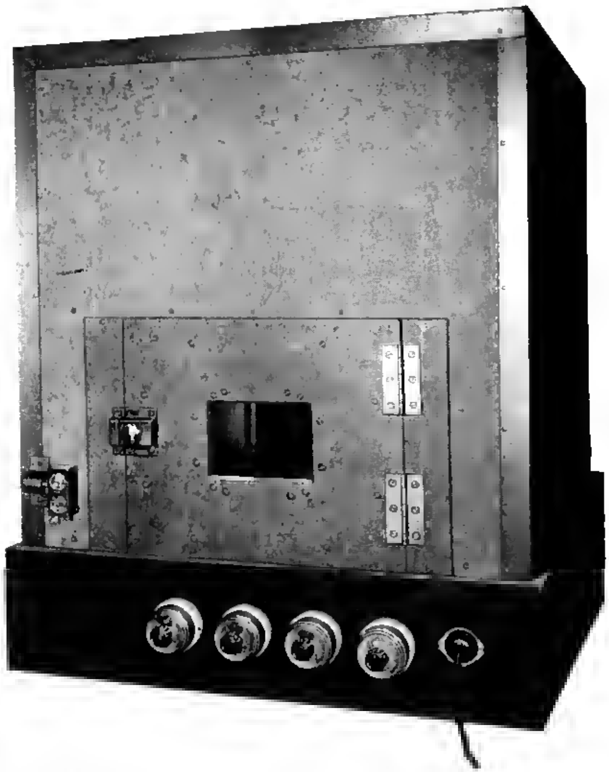

Fig. 7—Flow-test apparatus of Fig. 6 enclosed for temperature control.

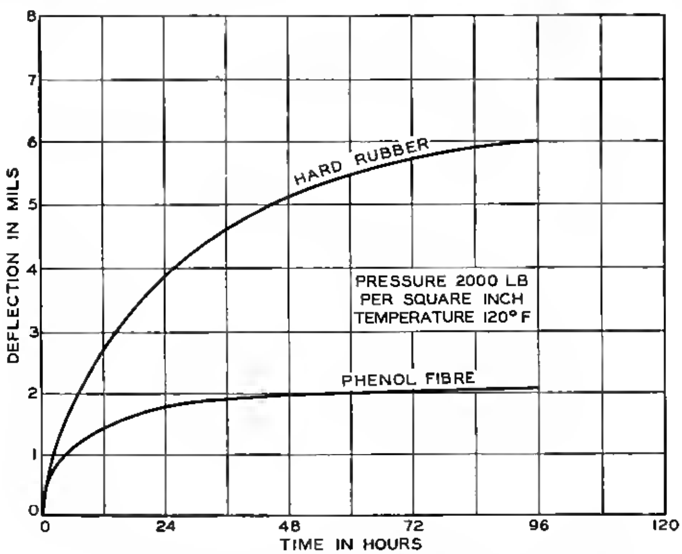

Fig. 8—Flow-test results for hard rubber and phenol fiber.

shown in Fig. 7, so that the temperature throughout the 24 hour test may be maintained at 120° F. corresponding to the maximum likely to be experienced in service. The amount of shrinkage or flow is measured on the dial previously shown. Fig. 8 shows the relative performance of hard rubber and phenol fiber under the conditions of this test.

Molded Plastics

In recent years there has been great activity on the part of manufacturers of molded plastics to develop improved molding compounds, and we have endeavored to keep informed of new developments by examining new compounds as they became available. An interesting problem presented itself in the application of suitable molding compounds to a device known as a test strip, shown in Fig. 9. It will be

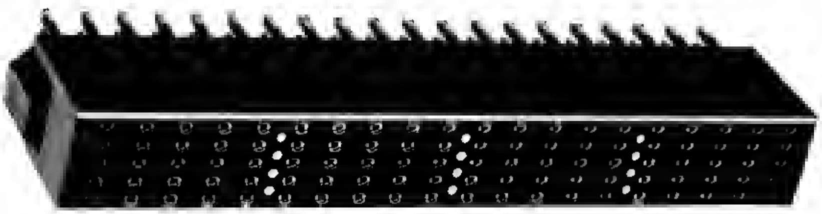

Fig. 9—100 point test strip used in switchboards.

seen that it consists of a number of metal terminals mounted flush on the face of the strip and projecting at the back to provide soldering lugs for the central office wiring. In operation it is necessary to touch a metal contact plug to the appropriate test strip contact which will produce an audible signal in the operator's receiver. In passing the plug over "live" terminals an arc is drawn out, which is accentuated by a habit of some operators of running their pencils along the grooves leaving a conducting path. Such arcs caused permanent conducting paths in the surface of the bakelite, despite the adoption of strenuous cleaning routines. The need for a better insulating material for this use became even more urgent with a demand for a test strip having 200 terminals instead of 100 in the same space.

Studies of compounds having such base materials as cellulose-nitrate, shellac, hard rubber, casein, and cellulose-acetate showed the last mentioned to give desirable arcing resistance. Foreign conducting material on the surface was burned off by the arc; the products of combustion of the small amount of cellulose acetate actually burned by such an arc are largely volatile, and the residue is non-conducting.

The compound used was found not to be sufficiently heat resistant to be satisfactory for the body of the test strip. The problem was solved by using it as a veneer on the test face of the bakelite strip.

This face is farthest from the heated ends of the terminals, is free from mechanical strain and is therefore not damaged by soldering operations. Since it was the practice to mold this test strip using several partially cured preforms, the veneer construction was introduced with only a slight increase in cost. The cellulose acetate has nearly the same molding temperature as the phenol plastic, so that the composite test strip could be molded in one operation. Fig. 10 shows the appearance

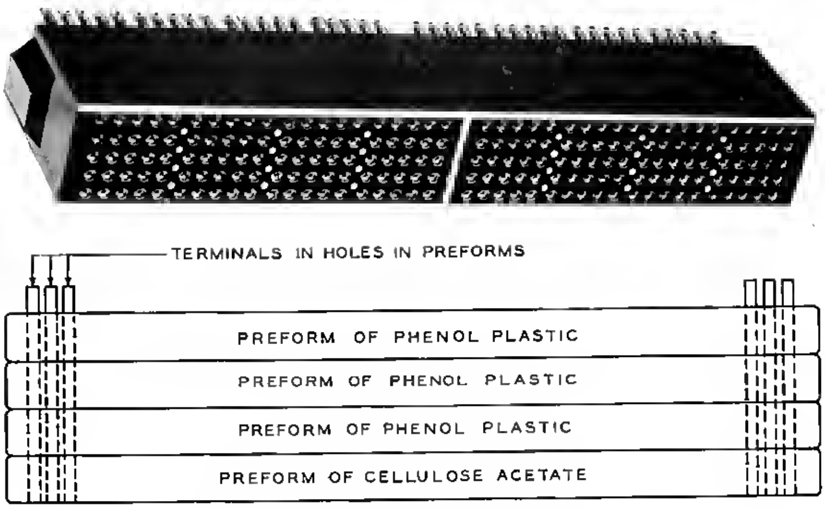

Fig. 10—Method of molding composite 200 point test strip.

of the modified test strip and the method of molding.

Textile Insulation

Another development was in the improvement of textile insulation which was recently described before the Institute.[2,3] It is mentioned here only in passing, because of its great commercial importance.

As a result of several years of study in the laboratory, it was found that the insulating quality of textiles depended on (1) the kind of fiber; (2) impurities present in the fiber; (3) moisture. The salts of sodium and potassium were found to be highly detrimental from an insulation standpoint. A very great improvement was effected by a washing treatment of the textile. Thus it has been possible to make

[2] "The Predominating Influence of Moisture and Electrolytic Material Upon Textiles as Insulators," R. R. Williams and E. J. Murphy, *Trans. A. I. E. E.*, Vol. 48, 1929.

[3] "Purified Textile Insulation," H. H. Glenn and E. B. Wood, *Trans. A. I. E. E.*, Vol. 48, 1929.

cotton an acceptable substitute for silk as wire insulation, as well as to improve greatly the insulating properties of silk. In one instance, central office distributing frame wire, of which the Bell System uses about five hundred million conductor feet annually, it was found possible to use double silk insulated conductor of treated thread where formerly triple silk insulation was required. An actual improvement in insulation was effected at the same time that a considerable economy resulted.

Metallic Materials

Non-Ferrous Metals

Telephone apparatus uses about 30,000,000 lbs. yearly of brass, bronze and nickel silver as structural members, springs and bearings. Because of space limitation the parts are necessarily small, many are formed into irregular shapes; spring parts must maintain accurate adjustment and have long fatigue life; certain other parts must resist wear. Experience with commercial grades of brass indicated wide variations under existing specifications and unsatisfactory means of testing the quality. At first blush there may not appear to be any connection between the temper of a metal spring and the grade of telephone service furnished, but looking at the matter broadly we were convinced that the stakes were large enough to warrant our launching an investigation of non-ferrous metals with the object of arriving at a better purchasing specification. Accordingly the Bell Telephone Laboratories initiated a joint study with the Western Electric Company and the American Brass Company which has extended over a period of several years. The results of this work have been described in considerable detail in appropriate papers before the American Society for Testing Materials.[4,5]

This has resulted—

1. In a more accurate knowledge of the physical properties of brass, phosphor bronze and nickel silver.
2. Development of improved methods of test.
3. Preparation of better purchasing specifications with resulting improved control of the quality of the materials.

As an instance of the benefits derived, the work on hardness testing may be cited. For many years the scleroscope had been used as a rapid means of controlling the quality of sheet metal but trouble was frequently encountered because results could not be readily duplicated on

[4] "Physical Properties and Methods of Test for Sheet Brass," H. N. Van Deusen, L. I. Shaw and C. H. Davis, *Proc. Amer. Soc. for Testing Materials*, 1927.

[5] "Physical Properties and Method of Test for Sheet Non-Ferrous Metals," J. R. Townsend, W. A. Straw and C. H. Davis, *Proc. A. S. T. M.*, 1929.

different instruments and it was necessary to allow rather wide limits on each temper resulting in considerable overlapping of the temper tolerances. While tensile strength is usually considered the reference test for cold worked metal, it is necessary to have a test which can be used for more rapid inspection. As a result of our study we were able

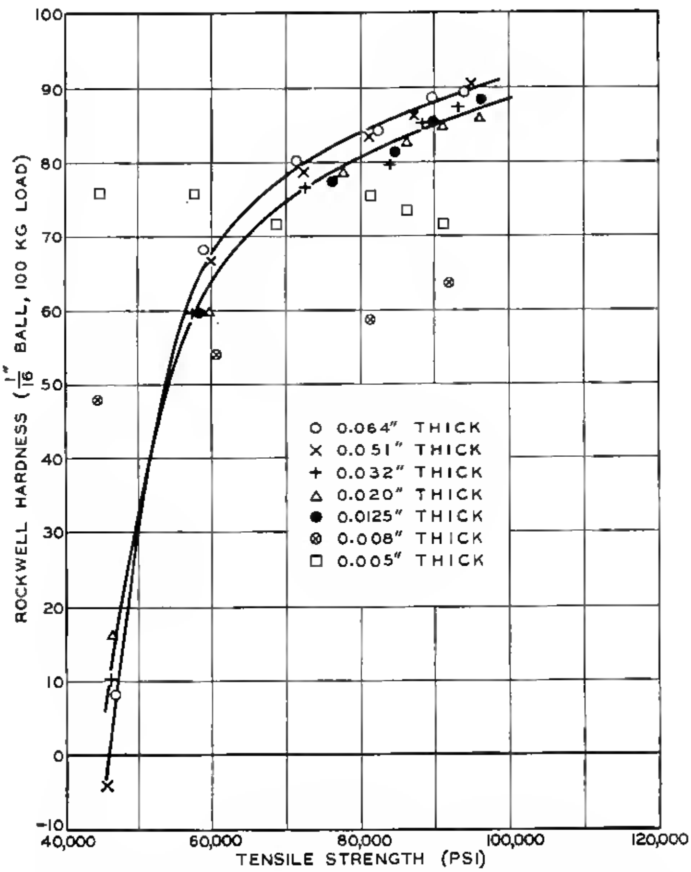

Fig. 11—Relation between tensile strength and Rockwell hardness—sheet brass.

to develop means for maintaining the Rockwell hardness tester to an accuracy within 2 points compared with 8 or 10 points on the scleroscope. Fig. 11 shows the relation between tensile strength and Rockwell hardness for a rolling series made up by the American Brass Company under carefully controlled manufacturing conditions. This rolling series covered all ranges of hardness and thickness of sheet metal generally used in telephone apparatus. The tension test is used

as a reference test and is resorted to only when the Rockwell test indicates the material to be close to the limiting values specified.

Work has been completed, resulting in the preparation of improved specifications for leaded brass, annealed brass, nickel silver and phosphor bronze and a similar investigation of rod stock in all grades of these metals is now under way. It is interesting to note in passing

Fig. 12—Rotary selector used in dial system.

that in the course of our investigations we determined that the endurance limit of non-ferrous metals is only half that established for ferrous metals, averaging approximately ¼ of the ultimate strength.[6]

For one of the rotary selectors used in the panel dial system we developed a leaded phosphor bronze sheet containing approximately 3 per cent of lead which proved very valuable in terms of increased

[6] "Fatigue Studies of Non-Ferrous Sheet Metals," J. R. Townsend and C. H. Greenall, *Proc. A. S. T. M.*, 1929.

life of the switch. This selector consists of an arrangement of closely spaced terminals referred to as the "bank" and a set of rotating brushes contacting with the bank terminals as shown in Fig. 12. Experience in the field indicated that under severe service conditions these selectors have a comparatively short life. As a result of our studies we replaced the brass brushes in the rotor with phosphor bronze, and the brass terminals of the bank with leaded phosphor bronze, a combination which has given approximately four times the life obtainable with brass parts, with corresponding maintenance savings. The reduced wear seems to be due in part at least to a lubricating effect of the lead constitutent in the bank terminals.

Aluminum alloys have had considerable application to telephone apparatus not only in die castings but in sheet form as diaphragms in certain of the new developments in telephone transmitters and receivers. One of the most interesting of the aluminum alloys is duralumin, an alloy of aluminum, copper, silicon and magnesium. This material has about one-third the specific gravity of steel and like steel can be increased in strength by heat treatment in the manufactured form. Our first application of duralumin was as a stretched diaphragm in radio broadcasting transmitters. Here it was necessary to obtain material with as small a mass as possible and with the necessary strength to allow stretching to give a high natural period essential for good quality transmission. The material used in this case was 1.7 mils thick and had a tensile strength between 70,000 and 80,000 pounds per square inch.

Probably one of the most difficult applications of sheet duralumin is to the light valve used in the film method of sound picture recording. The light valve is an electromechanical device actuated by amplified speech currents, and consists of a loop of duralumin tape supported in a plane at right angles to a magnetic field. A view of the light valve is given in Fig. 13 which shows the tape held by two wind-lasses, AA^1, at one end, and wrapped over a spring-supported pulley B at the other. This places the tape under considerable tension. The tape is 6 mils wide and .5 mil thick. The central portion of the loop is supported on insulating bridges just above the face of the pole piece which constitutes the armature of an electromagnet.

Viewed against the light, the valve appears as a slit 2 mils wide by 256 mils long. In operation the amplified speech current is passed through the duralumin tape which, reacting with the magnetic field of the electromagnet causes variations in the width of the slit controlled by the variations in the speech current. The light beam directed toward the film is thus modulated by the slit in accordance with the variations

of the speech current. In order to avoid distortion, severe requirements were imposed on the straightness of the edges of the tape, and on the strength, in order to permit stretching to give a natural period in excess of 7,000 cycles per second. To obtain these properties special heat treatments and methods of rolling the material had to be developed.

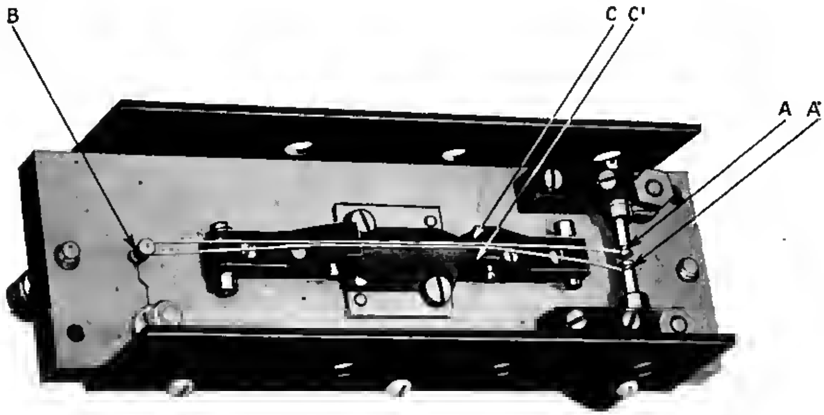

Fig. 13—Light valve used in recording of sound pictures.
AA^1—Wind-lasses.
B—Pulley supported by spring.
CC^1—Insulating bridges.

Ferrous Metals

Some interesting problems have been encountered in the use of ferrous metals in telephone apparatus, particularly in the operator's calling dial. Considerable trouble was encountered from slippage of the dial governor resulting from premature wear or breakage of the tips of the pawls or the teeth of the pinion. These parts had been made out of low carbon steel which had been found satisfactory for the subscriber's dial. The operator's dial, however, being used for a greater number of times, presented a more severe condition and case hardening was applied to obtain better wear resisting properties. This treatment was found to be unsatisfactory because the parts have thin sections and the combined weight of the two parts amounts to only 2 grams. Case hardening either produced too deep a case giving brittleness or too shallow a case which soon wore through. A nickel-chrome steel, originally developed for the automotive industry was finally adopted for the pawl and pinion combined with a special heat treatment. It was thus possible to obtain a useful life of 8 million operations as compared with an average of ½ million operations for the steel formerly used. This is another instance in which an increase

in first cost resulted in appreciable savings in annual cost of the device, considered from the operating companies' standpoint.

Ferro-Magnetic Metals

Up to about 15 years ago, telephone engineers used the magnetic materials in their designs which had been originally developed for the power industry, viz., magnetic iron and silicon steel. An exception was the use of 4. mil hard drawn steel wire for loading coil cores where extremely low permeability was desired.

The increasingly severe requirements imposed by compositing and phantoming of telephone circuits and the introduction of vacuum tube

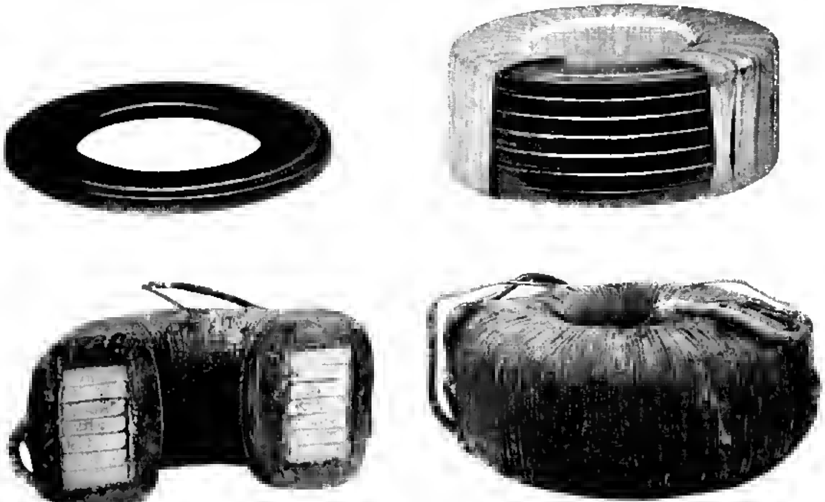

Fig. 14—Loading coils showing core rings of highly compressed powdered iron.

repeaters, made necessary the development of materials which would more adequately meet the new requirements. It was in 1915 that the Western Electric Company first produced compressed powdered electrolytic iron cores for loading coils. The construction of such powdered iron core coils is illustrated by Fig. 14. Electrolytically deposited iron is ground to a fine powder; the particles are covered with an insulating film and then compressed at a pressure of 200,000 lbs. per square inch to form rings as shown in the figure. This material was sensational in the improvements which it afforded over the core materials theretofore available as it combined with extremely high resistivity, high stability of A.C. permeability under conditions of powerful superposed or residual D.C. magnetization. The change in

A.C. permeability resulting from the temporary application of large magnetizing forces did not exceed 2 per cent as compared with changes of the order of 30 to 40 per cent commonly found in previously available materials.

The next important step was the discovery of permalloy, a nickel-iron alloy having extremely high permeability which had its first application in the loading of submarine telegraph cables. This material with its extremely low hysteresis loss and high induction for feeble magnetizing forces, has since been applied extensively in the design of transformers, relays, receivers, and other telephone apparatus. Fig. 15

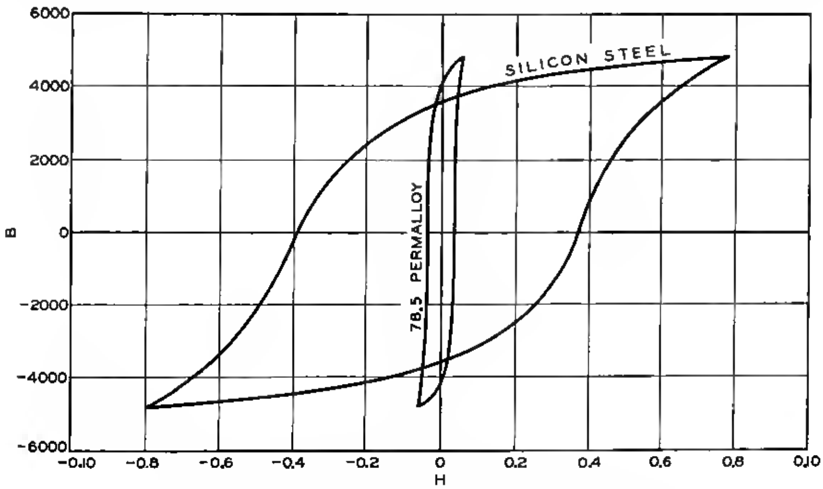

Fig. 15—Hysteresis loops of silicon steel and permalloy.

shows comparative hysteresis loops for permalloy and silicon steel. The much smaller hysteresis loss of permalloy, approximately one-seventh of that of the silicon steel sample is indicative of its greatly reduced tendency to remain magnetized after the removal of a magnetizing force, a property which is of great importance in the operation of quick release types of relays. In transformers and in continuously loaded cable, the very high permeability at small magnetizing forces of this material, strikingly shown in Fig. 16, is of great value. It is the high permeability of permalloy that made it possible to load telegraph cables successfully and thereby attain a threefold increase in telegraph speed. In transformers such as those used in vacuum tube amplifiers, the high permeability permits the designer either to achieve equivalent quality with a much smaller apparatus volume or, in the same space, to furnish equipment of better quality. The latter result is shown by the curves of Fig. 17 which indicate how transformer performance at

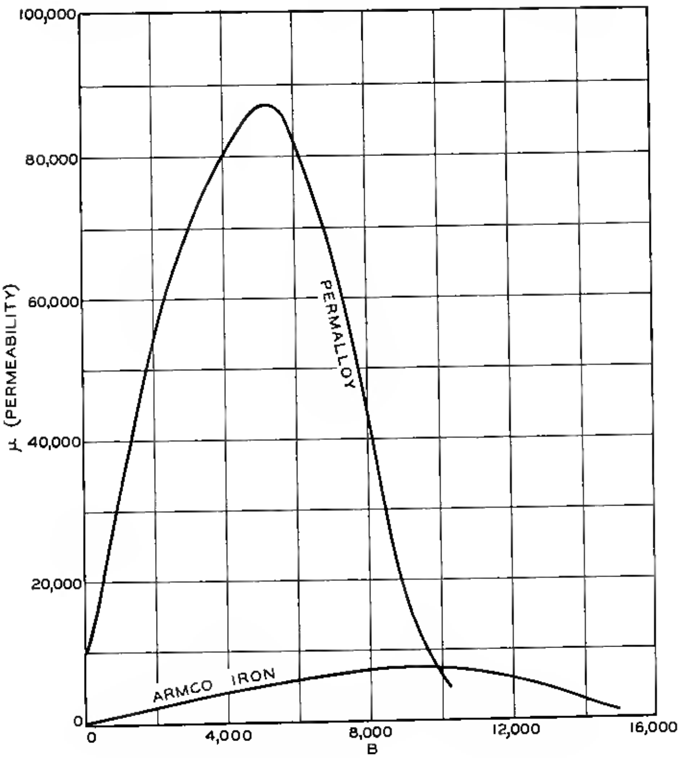

Fig. 16—Permeability curves of soft iron and permalloy.

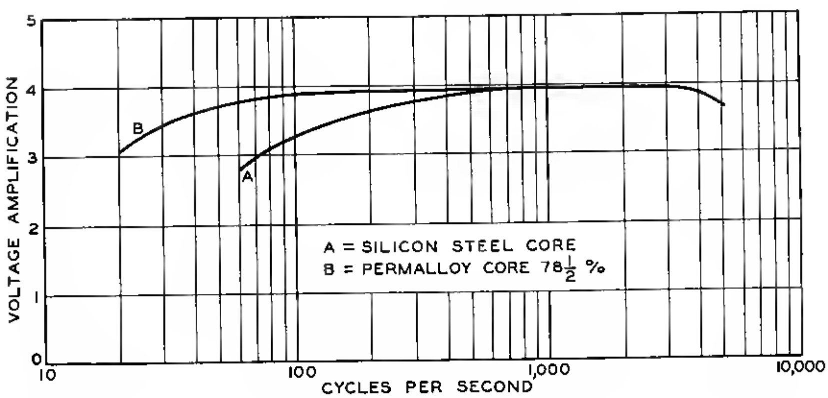

Fig. 17—Showing improvement in quality of voice frequency amplifier due to permalloy core transformers.

very low frequencies is improved by the use of permalloy. Sheet permalloy has been followed by compressed powdered permalloy[7] and this by perminvar,[8] the newest member of the magnetic alloy family.

Compressed powdered permalloy has replaced the powdered iron as it has all of the desirable properties of the latter and to an even greater degree. By virtue of higher permeability combined with lower hysteresis loss, it has made possible the design of smaller coils of superior performance characteristics. As an illustration the two loading coils of Fig. 18 are shown, the smaller of these being the electrical equivalent

Fig. 18—Relative size of powdered iron (left) and powdered permalloy (right) loading coils.

of the larger in all respects and in some its superior. In general the reduction in coil size made possible by the use of powdered permalloy in place of powdered iron amounts to about 75 per cent giving very substantial savings in manufacturing costs, handling problems and installation space required.

Perminvar is remarkable in an entirely unique respect. Its permeability is not exceptionally high, being of the same order as that of ordinary soft iron at moderately low magnetizing forces, but it is exceptionally constant with respect to magnetizing forces. This is shown in Fig. 19 from which it will be noted that there is substantially no change in permeability up to a force of about 2 gausses whereas over this same range, the permeability of soft iron undergoes a change of more than 2,000 per cent. Up to somewhat smaller magnetizing forces, perminvar has a vanishingly small hysteresis loss. Fig. 20 depicts this loss for perminvar. It is to a material of constant permeability and low hysteresis loss that the transformer designer turns when he has a difficult requirement as to low modulation to meet. Unfortunately, while perminvar has these properties over a limited range of magnetiza-

[7] "Compressed Powdered Permalloy, its Manufacture and Magnetic Properties," W. J. Shackelton & I. G. Barber, *Trans. A. I. E. E.*, Vol. 17, 1928.
[8] "Magnetic Properties of Perminvar," G. W. Elmen, *Jour. of Franklin Institute*, Vol. 206, 1928.

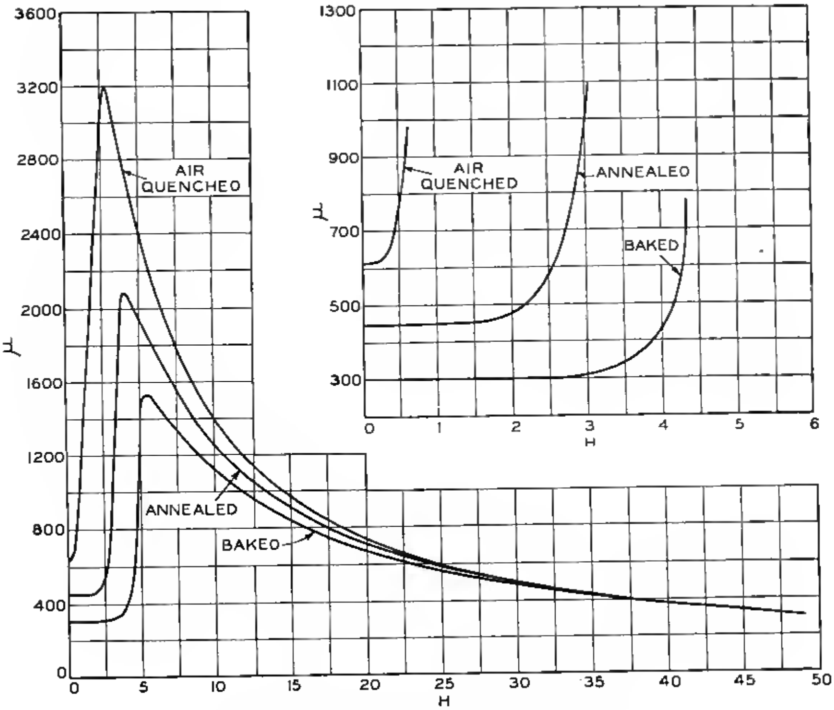

Fig. 19—Permeability curves for perminvar.

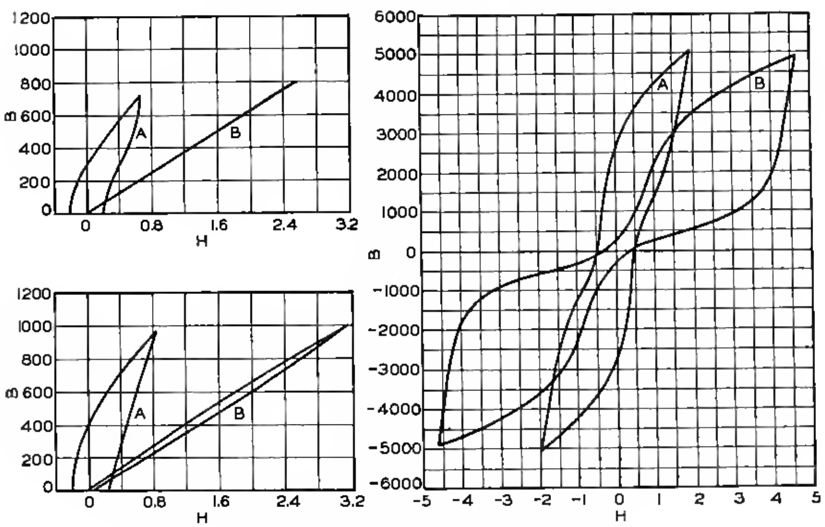

Fig. 20—Hysteresis loops for perminvar.
A—Air quenched.
B—Baked.

tion, if this range is exceeded they are lost and so it is necessary that it be used within suitable limits.

These materials have been described in technical papers before various scientific societies and are not, therefore, discussed in detail here.

As indicating the wide scope of magnetic performance that is demanded of materials for use in communication apparatus, some of the necessary properties are listed below:

High permeability—at very feeble and at high inductions.
High saturation value of induction.
Low residual magnetization.
Low hysteresis loss at feeble and moderate magnetizations.
Low eddy-current losses over the frequency range from 0 to 80,000 cycles.
High constancy of permeability over a wide range of magnetization.
Small effect on A.C. permeability at feeble currents with superposed or residual D.C. magnetization.

Certain of these requirements are imposed from the simultaneous transmission of D.C. telegraph currents, speech currents and carrier frequency telephone or telegraph currents through the transformers, loading coil or other iron-core apparatus in the circuit. Interference between channels, due to magnetic modulation in the cores, must be kept at an extremely low value for satisfactory quality of transmission.

Summing up our work on materials, the results have been along two general lines: (1) improvement in quality of commercial materials and (2) development of new materials. As regards the first, we have worked in close cooperation with material suppliers whose progressive attitude has made possible certain of the advances described. The more striking advances have been due to the discovery of new or improved materials in our laboratories, the savings from which have amply justified the program of continuous research which has been the Bell System policy for a number of years. To take a single instance, the field of magnetic alloys—probably the first to which we applied intensive effort,—a single invention, the powdered electrolytic iron core resulted in savings of such magnitude as to far overshadow the cost of the investigational work. As already noted, this material has since been superseded by the powdered permalloy core which represents an equally great advance.

There is one point which should be emphasized and that is, that the most economical material is not necessarily the cheapest one. Treated textiles cost more per pound than ordinary textiles; permalloy costs more per pound than silicon steel. In these particular instances so

much less material is required to obtain the desired result that there is a net saving in cost of manufacture. The true criterion of relative economy, however, takes into account not alone the cost of manufacture, but the serviceability of the device throughout its operating life. Hence the designer, if he be free to decide on purely engineering grounds, will make his decision as to the best materials to use on the basis of the lowest annual charge over a period of years, thus taking into account the important item of maintenance cost.